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This final report briefly describes the construction and installation of an in situ MBE cleave-edge overgrowth apparatus and accomplishments in the following two research areas: (1) Novel cleaved-edge overgrowth structures for tunneling into and between one-dimensional (1D) and two-dimensional (2D) electron systems, and (2) the Terahertz emission from and the emission spectroscopy of low dimensional electron systems.

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From March 1, 1993 through January 31, 1997

Low-dimension Electronic Processes in High Mobility GaAs/Al_x Ga_{1-x}As Nanostructures

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Abstract

This is a final report on the research carried out under ARO grant DAAH04-93-G-0071 for the period of March 1, 1993 to January 31, 1997. It briefly describes the construction and installation of an in situ MBE cleave-edge overgrowth apparatus and accomplishments in the following two research areas: (1) Novel cleaved-edge overgrowth structures for tunneling into and between one-dimensional (1D) and two-dimensional (2D) electron systems, and (2) the Terahertz emission from and the emission spectroscopy of low dimensional electron systems.

Low-dimension Electronic Processes in High Mobility GaAs/Al_x Ga_{1-x}As Nanostructures

Apparatus Construction

We fabricated a simple sample cleaver, similar to the design of Pfeiffer and West at Bell Labs, for in situ MBE cleaved-edge overgrowth. It is essentially a Ta bar which can be brought into contact with the GaAs wafer right in front of the MBE ovens during the growth. The GaAs 9100) wafer already contains a multilayer GaAs/AlGaAs structure, grown in a previous MBE growth, is thinned to about 100um, has a small scratch at the position to be cleaved, and is remounted on a Mo block with its edge [the (110) face] facing the MBE ovens. In the MBE growth chamber, the Ta bar is pressed against the (100) face of the wafer to cleave so that a fresh (110) edge surface is now exposed to the MBE ovens. We can then grow on a clean edge.

Research Accomplishments

1. <u>Electron Tunneling in low-dimension systems from cleaved-edge overgrowth.</u>

Quantum confinement to less than two dimensions is conventionally achieved by gating or etching of an epitaxially grown two-dimensional (2D) electron system, which inevitably introduces uncertainty in the shape, strength and homogeneity of the confining potential. We used the cleaved edge overgrowth (CEO) technique and succeeded fabricating device structures in which the confining potential profiles are abrupt, of known strength, and precise to atomic scale. We investigated the novel electron tunneling processes in such structures and demonstrated a new negative transconductance device which we dubbed the SRETT.

1.a. Tunneling into one- and two-dimensional systems.

We fabricated novel electron in-plane tunneling systems in GaAs/Al_xGa_{1-x}As using the technique of cleaved edge overgrowth, and made tunneling measurements into both one- and two-dimensional (1D and 2D) systems. Our devices demonstrate tunneling through an abrupt molecular beam epitaxially defined barrier where the shape of the barrier potential is exactly known. We investigated three different in-plane tunneling geometries, namely 2D–1D–2D, 2D–2D and 2D–3D, and obtained intrinsic current vs. voltage characteristics for all three geometries. Tunneling spectroscopy on the 2D-3D devices made it possible to unambiguously identify that, among the many theoretical explanations for the so-called Hickmott oscillations of LO-phonon emission in transport through semiconductor heterojunctions, only the Grinberg-Luryi model is tenable.

1b. The surface resonant tunneling transistor (SRETT).

The SRETT is a three-terminal device exhibiting negative transconductance as well as negative differential resistance. The device, whose I-V characteristics arise from resonant tunneling of 2D electrons through the subbands of a 1D-electron wire, is a potential alternative to current CMOS technology and can also provide new logic applications.

2. Terahertz Emission.

Emission in the terahertz spectral region by hot carriers in low-dimension systems was systematically investigated. Spectroscopy of the terahertz emission was accomplished by the combination of a composite Si bolometer and a magnetic-field-tuned electron cyclotron resonance filter. We find that in a homogeneous 2D electron system, the emission spectrum is that of a blackbody and the effective blackbody temperature of the hot electrons is quantitatively explained by a theory of acoustic and optical-phonon emissions. When a grating coupler is fabricated on top of the 2D sample, narrow band (~0.2 THz at FWHM) emission from radiative decay of 2D plasmons is observed. The observed energies are in good agreement with the calculation that properly takes into account of screening by the grating.

In the case of ID wires, an inter-subband plasmon resonance is observed on top of the Drude block-body background. The energy and linewidth of the resonance are direct measures of the 1D quantum confinement and the quantum level width.

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